METHODS FOR TRANSPORTING KAONS TO BUBBLE CHAMBERS AT FERMILAB

J. R. Albright

19 August 1975

1. INTRODUCTION

This note is a review of various methods that have been proposed for beams of charged and of neutral kaons to be used in bubble chamber experiments. The reader is assumed to be familiar with the basic terminology associated with the N3 and N5 beams.[1,2]

So far there are no plans to produce separated beams of kaons at Fermilab energies; instead emphasis has been placed on the concept of enriched beams.[3] For charged particles this means that there will be some contamination in the beam, but the contamination will be identified by counters and wire chambers on a track-by-track basis. The enrichment, of course, refers to the use of various strategems to improve the ratio of wanted to unwanted particles so as to avoid undue waste of film and running time.

2. NEUTRAL KAONS

As long ago as 1969 the idea was proposed[4] that by double targeting one can make K_L^o mesons from the sequence

$$p \rightarrow \pi^- \rightarrow K_L^o$$

Additional interest in this idea was stimulated[5] by the decision to include large iron toroidal magnets in the new Lab E, beyond Enclosure 113, since these toroids offer a neat solution to a nasty problem - how to get rid of the large number of muons produced by decay in flight of the π^- in the intermediate stage of the beam.

It is assumed that about 10^{11} protons are incident on target 3T in Enclosure 100. The yield of π^- at the first target can be predicted with reasonable accuracy by using the data of Aubert et al[6] for protons incident on aluminum or from Baker et al[7] for protons on beryllium. The results are shown in Fig. 1 for the assumption that the incident protons have momentum equal to 300 GeV/c. It is assumed that 10^{11} protons are incident on the target, that the momentum bite is 1% and that the solid angle is 3×10^{-7} sr. In each case the target was 30 cm in length.

The N5 beam is then used to transport the negative beam - almost all π^- - to Enclosure 113, where the beam is brought to a double focus about 25 feet from the upstream end of the enclosure. Fig. 2 shows a schematic view of the beam. Table I shows the gradients of the quadrupoles that will achieve this focus for p=140 GeV/c. The focus is rather easy to obtain; one eases off on the quadrupoles in Enclosure 109, thereby sliding the focus from the usual position in Enclosure 111 to the new target location in Enclosure 113. Notice that the field lenses in Enclosure 103 have been turned off; there is a slight gain in the acceptance of the beam as a result. The limiting apertures are determined horizontally at 5F09 and vertically at 3D01. The solid angle seen by the entire beam is about 3×10^{-7} sr. The data of Fig. 1 with this aperture leads to the conclusion that a few more than 10^4 pions can be transported.

Unfortunately the yield of K_L^o at the second target is not easy to estimate. There are two sources of data. One source is the yield curves for

$$\pi^+ p \to K_s^o + \text{anything}$$

at 22 GeV/c in the 80-inch bubble chamber at Brookhaven.[8] Scaling these results indicates that there will be plenty of K_L^o even for a small solid angle because the momentum bite is very large. The other source of information is from Fermilab Experiment 234

$$\pi^- p \to K_S^o + \text{anything}$$

at 250 GeV/c in the 15-foot bubble chamber. These results are shown in Fig. 3; statistics are very low, but they provide grounds for optimism when it is realized that the events shown include only those K_s^o with opening angle large enough to allow visual separation from $\gamma \to e^+e^-$. It is evident that choosing a small production angle will cut down on the number of slow kaons without much affecting the fast ones.

In accordance with the suggestions of Pruss[5], the target is to be followed by a 20-foot sweeping dipole at 18 kG to eliminate the charged particles coming from the target. Toward the end of Enclosure 113 there should be a lead gamma converter followed by another sweeping dipole. There should also be provision for adding some polyethylene absorber to cut down on the number of neutrons. The exact amounts of Pb and $(CH_2)_n$ to be used will depend on the answers to the following questions:

a) How many K_L^o will be produced per π^-?

b) How many π^- will be permitted in Enclosure 113 before radiation safety becomes an important issue?

Since the radiation length in Pb is 0.56 cm and the nuclear collision length is 9.8 cm, it is clear that several radiation lengths of Pb will not deplete the kaons too badly.

The iron toroids in Lab E will serve to define the solid angle of the neutral beam. They have a hole in their center that is a square 5 inches on a side. The last of these is 256 feet from the target, so that 2.65 μsr will be the solid angle seen by the bubble chamber. The largest production angle will be 0.8 mr. The beam will be about 19 cm wide at the center of the bubble chamber.

The most important function of the toroids is to cut down on the number of μ^- tracks in the chamber. For example, if 6×10^4 π^- are transported at 140 GeV/c one can expect about 7 of them to decay in flight for each meter of beam. Since the second target is 816 m from the first, this means that several thousand muons from an incoherent source will be headed in the general direction of a very large bubble chamber. If the toroidal magnets are energized with a clockwise magnetic field (as seen by an entering beam particle) they will deflect μ^- outward from the center of the beam. If P_μ = 180 GeV/c the toroids can provide 20 mr of bend, **which will** get most of the muons out of the way.

It should be mentioned that this arrangement for a neutral beam is very well suited for photoproduction experiments. By removing the Pb and $(CH_2)_n$ filters and reducing the flux of π^- there should be a good photon beam for which the energy peaks at just under half of the π^- energy. The small solid angle is of benefit here since photons produced at $\theta = 0 \pm .8$ mr have a sharper energy spectrum than those included if wider angles are used. This same advantage will probably also apply to the K_L^o beam. It may also help alleviate the problem of neutrons in the beam.

Pruss[5] includes a list of equipment needed to be added to N5 for the neutral beam:

1. Two 20-foot dipoles
2. Target station in Enclosure 113
3. Pb radiator
4. Vacuum pipes and He bags
5. Perhaps some radiation shielding in Enclosure 113.

To this list can be added:

6. $(CH_2)_n$ filter
7. Collimators, including some sort of plug for air gaps around the windings of the toroidal magnets
8. Some sort of monitor of beam intensity downstream of the second target. A useful possibility might be the small hadron calorimeter used by E31; this device could measure the total flux of K_L^o and neutrons as well as providing information on the momentum spectrum. The EMI may possibly

be of some use in estimating flux of K_L^o into the chamber. A lead-glass scintillator to count γ rays would be useful.

9. A thin aluminum port in the outer container (vacuum tank) of the bubble chamber would be needed if the beam were to be used for photons; it is not needed for K_L^o.

3. CHARGED KAONS

Of the methods suggested for charged kaons some are suited for either K^+ or K^- and some are unique to one or the other. These methods are reviewed individually in this section. Unfortunately, yield data are very scanty indeed for nearly all of these methods, so that a choice will be impossible until further testing can be done.

a. Filtering

The yield of K^+ from protons on a target is just barely high enough that it makes some sense to enrich a beam by adding $(CH_2)_n$ filter, taking advantage of the fact that π^+ and p have higher cross sections. Some tests have already been made with filtering in the N3 beam. The situation is discussed by W.W.Neale in his memorandum of 31 July 1975. This method is not useful for K^- because they are produced even less copiously than K^+, and the method appears to be marginal for K^+.

b. Superconducting Dipole

Negative hyperon beams have been used at BNL[9] and CERN[10] using a dipole without any focusing. At both laboratories they find results that are shown qualitatively in Fig. 4 - at large values of x the Σ^- are produced more copiously than π^-; (x is the Σ^- momentum divided by the incident proton momentum). This result suggests that a beam of Σ^- could be targeted to make K^-. The major problem is the short lifetime of the Σ, requiring a short beam.

A superconducting dipole without any focusing could in principle be placed in Enclosure 100 and used to separate positive particles from negatives, dispersing the negatives such that a small second target would see only the high-momentum negatives in which the Σ^- are numerous. The advantages are: few changes in the system, and short pathlength of the Σ^-.

The disadvantages become evident if one considers the dispersion of available dipoles. (A superconducting dipole with a length of 1 m and a field of 4 T is under construction in the Neutrino Department.) Suppose that protons are incident at 300 GeV/c on the first target, then a Σ^- with $x = 1$ will be bent through 4 mr by the dipole. The crossover for π^- and Σ^- in the data of Badier et al[10] occurs at $x = .85$, corresponding to $p = 255$ GeV/c for which the bend is <5 mr. Thus, there would have to be very tight collimation in order to keep the π^- from swamping the experiment. The situation gets worse if the protons are incident at 400 GeV or above.

There are other difficulties:

a) the collimator needed to define carefully the angular acceptance would have to be long enough so that one would begin to lose the advantage of short length of the system.

b) Having bent the negatives through 4 or so mr, they would have to be bent back in order to get them into the channel for the N3/N5 beam.

c) The inadequate dispersion of the 1 meter, 4T superconducting dipole could perhaps be improved by building longer, more powerful magnets, but the prospects of gaining a factor of 4 or more in the near future are not optimistic.

d) Superconducting magnets will not tolerate a large heat load. All the positives, all the neutrals, and most of the negatives must be kept from hitting the magnet; adding a little bit of shielding only makes matters worse because of shower formation. Doubtless the only answer is to design a split superconducting dipole with a length >2 m and a field of 70 kG.

Because of these troubles, it seems clear that a dipole without focusing is not the best way to make K^-.

c. <u>RF Filtering</u>

It has been suggested that two widely separated RF cavities would deflect unwanted particles twice while providing two canceling deflections for wanted particles. This scheme is exactly the opposite of that used at BNL or SLAC. It is essentially a scheme for enrichment, not separation. The cavities that were used at BNL for Beam #4 to the 80-inch bubble chamber are not now in use and could probably be moved to Fermilab. The trouble with them is that their pulse length is altogether too short leading to two serious defects: a) one loses intensity because the spill must be very short, and b) tagging cannot occur in such a short time. These are just the reasons why the cavities are not being used in one of the counter beams at BNL; therefore, this idea will not work.

d. <u>Downstream Targeting</u>

The idea is to use the sequence

$$p \to \pi^{\pm} \to K^{\mp}$$

By targeting pions of charge opposite to that of the desired kaons one can eliminate the leading particle effect. As Neale has pointed out, this scheme would require only one change in the N3 beam: the addition of a threshold Cerenkov counter near the bubble chamber.

For N3 the beam of charged pions can be brought to focus 50 m upstream of Enclosure 112. The existing dipoles and quadrupoles can transport the enriched kaon beam from there to the bubble chamber.

For N5 the situation is less favorable. The natural place to have a target is in Enclosure 113 at the same place indicated for the K_L^o beam. The fact that the N5 line points directly at the bubble chamber was an advantage for the neutral beam, but here it is a disadvantage because of the need to get rid of the neutrals. A dog-leg will have to be designed for the region between 113 and the chamber if this method is to be used in N5. There appears to be no serious difficulty associated with such a design, but it has not yet been studied in detail.

The big question mark about this method for either K^+ or K^- is the K/π ratio that can be achieved this way. Yield curves for $\pi^+ \to K^-$ and $\pi^- \to K^+$ are just not available. It is clear that some simple tests can produce new information that will make or break this method for producing charged kaons.

e. Pulsed Quadrupoles

Neale has suggested[3] the use of double targeting in Enclosure 100 using pulsed quadrupoles to obtain the necessary focusing. As in the case of the superconducting dipole mentioned earlier, the idea is to use a Σ^- beam to make K^-. The inadequate dispersion of the dipole is essentially overcome by the chromatic aberration of the quadrupoles so that the low momentum π^- will miss the second target.

If one attempts to accomplish double targeting with 4 conventional 7-foot quadrupoles it quickly becomes apparent that there is not enough space in the downstream end of Enclosure 100 to get point-to-point focusing. Even if one were satisfied with nearly focusing the beam, the separation of the two targets would be so great that nearly all of the Σ^- would decay in flight. Pulsed quadrupoles have significantly higher gradients to overcome these problems.

An arrangement using 4 pulsed quadrupoles was arrived at by Neale and me. It is shown in Fig. 5. Each quadrupole is assumed to have the following properties:

length = 60 cm ≈2 ft

diameter (useful) = 2 cm

operating gradient = 400 T m^{-1}

maximum gradient = 500 T m^{-1}

The intertarget separation is about 12 m; at 250 GeV/c, 27% of the Σ^- will survive. At 350 GeV/c this figure rises to 35%. A certain amount of longitudinal chromatic aberration is built into the design in order to improve the yield. For incident protons at 300 GeV/c, the system will produce a vertical focus for secondaries at 250 GeV/c and a horizontal focus for 225 GeV/c.

There are numerous problems with this arrangement, but all of them appear to be capable of being overcome eventually. A few of these are listed here.

1) With pulsed quads one could have trouble tuning on slow spill. Of course, the entire downstream part of the beam can be tuned with pions on slow spill by initially tuning N7 to hit the second target rather than the first. Then the N7 beam can be retuned to hit the first target; the quadrupoles themselves

will have to be tuned on fast spill. The tune of the quadrupoles is not critical.

2) Multipulsing is not possible with this system. Actually the quads <u>are</u> capable of double pulsing, and it is unlikely that any more than that would be allowable because of radiation levels in Enclosure 100.

3) The quads will act as additional targets, producing a lot of background particles. This problem can be solved by judicious placement of about a meter of tungsten in the vicinity of the second dipole in order to block those background particles that will actually get through the rest of the beam line.

4. RECOMMENDATIONS

It appears that the various activities for kaon beams are widely varying in their difficulty and in their probability of success. Thus, the things that are easy and informative should be done first even though they may not be the best way to proceed eventually. The following sequence seems logical:

a. Test the downstream pion targeting method of producing $K^{\pm}$. If it works one then can run $K^{\pm}$ in the 30-inch chamber, and the dog-leg design for N5 should be completed.

b. Test the neutral beam. It will be convenient to test γ and K_L^o in the same running period, since they require almost identical setups. This testing should be made with the 15-foot chamber running. The liquid need not be pure hydrogen.

c. If the tests in part a fail to give good K/π ratios with enough total flux, the pulsed quadrupoles in Enclosure 100 should be pushed, since that scheme has a high probability of working if pushed hard enough.

Even if the tests of part a) prove successful, it may still be worthwhile to continue the effort with pulsed quadrupoles for several reasons. The downstream targeting may work better for K^+ than for K^- because of proton contamination of the intermediate π^+ beam for the K^-. The downstream targeting appears to be more suitable for slow kaons, and the pulsed quadrupoles are more suitable for fast kaons; so the two methods may turn out to be complementary. Experience with pulsed magnets is likely to be useful for future efforts, such as Σ^- beams.

5. ACKNOWLEDGMENTS

I am grateful to the Neutrino Section of Fermilab for their kind hospitality during the time these studies were being made. I am especially indebted to Lou Voyvodic, Stan Pruss, Marvin Johnson, Bill Neale, and Gordon Koizumi for advice, ideas, data, and encouragement.

REFERENCES

1. J.Lach and S.Pruss; Fermilab Report TM-285 (1971), "Hadron Beams in the Neutrino Area".

2. J.E.Lannutti; Note on N3 and N5 beams.

3. W.W.Neale; Fermilab Report FN-259 (1974), "Enriched Particle Beams for the Bubble Chambers at the Fermi National Accelerator Laboratory.

4. R.A.Zdanis; 1969 NAL Summer Study, Vol. 1, p. 187. See also Brookhaven, Florida State, and Vanderbilt collaboration, Fermilab Proposal 65 (1970).

5. S.Pruss; "Conceptual Design of Neutral Beam Facility for 15-Foot Bubble Chamber".

6. B.Aubert, A.Benvenuti, C.Rubbia, L.Sulak, L.Koester, T.Roberts, R.Sard, T.Coffin, R.Diamond, R.French, W.T.Ford, T.Y.Ling, A.K.Mann, D.Cline, R.Imlay, R.Orr, D.D.Reeder, G.Koizumi, R.Stefanski, and H.White; FERMILAB-Conf-75/31-EXP, "Hadron Production at 0.8 Mrad by 300 GeV Protons Incident on a Thick Aluminum Target".

7. W.F.Baker, D.P.Eartly, G.Giacomelli, P.F.M.Koehler, K.P.Pretzl, S.M.Pruss, A.A.Wehmann, A.S.Carroll, I-H Chiang, T.F.Kycia, K.K.Li, P.O.Mazur, P.M.Mockett, D.C.Rahm, R.Rubenstein, and O.Fackler; NAL-Pub-74/31-EXP (1974).

7. D.J.Crennell, H.A.Gordon, M.I.Iffredo, and K.W.Lai; Phys. Rev. Letters 28, 643 (1972). Ot her sources of data exist; in E-8 at Fermilab yields have been measured for $p + Cu \to K_s^o$ + anything for $p_o = 300$ GeV/c; the momentum distribution does not agree well with Crennell et al. From E-234 the yield data of $\pi^- p \to K_s^o$ + anything at $p_o = 250$ GeV/c are troubled with poor statistics and with the suspicion that fast forward kaons are being missed in the scanning.

9. V.Hungerbuehler, R.Majka, J.N.Marx, P.Némethy, J.Sandweiss, W.Tanenbaum, W.J.Willis, M.Atac, S.Ecklund, P.J.Gollon, J.Lach, J.MacLachlan, A.Roberts, R.Stefanski, D.Theriot, and C.L.Wang; Phys. Rev. Letters 30, 1234 (1973).

10. J.Badier, R.Bland, J.C.Chollet, T.Devlin, J.-M.Gaillard, J.LeFrancois, B.Merkel, R.Meunier, J.-P.Repellin, G.Sauvage, and R.Vanderhaghen; Phys. Letters 39B, 414 (1972).

TABLE I

QUADRUPOLE SETTINGS TO OBTAIN A DOUBLE FOCUS IN ENCLOSURE 113

MAGNET	DISTANCE FROM TARGET (ft)	GRADIENT (kG/in)
3D01	319.8	-2.36778
3F01	387.8	2.14909
3F03	1061.5	0
3D03	1096.0	0
5F05	1584.2	2.51559
5D05	1662.7	-3.15014
5F06/1	1787.8	1.30
5F06/2	1799.3	1.30
5F09	2215.6	2.27581
5D09	2288.6	-2.31133
5D13/1	2714.5	0
5D13/2	2721.6	0

FIGURE 1. Yield of π^- from protons. Data on Al are from Aubert et al. (Ref. 6); data on Be are from Baker et al. (Ref. 7). It is assumed that 10^{11} protons at 300 GeV/c are incident on a 30 cm target; the momentum bite is 1%; the solid angle is 3×10^{-7} sr.

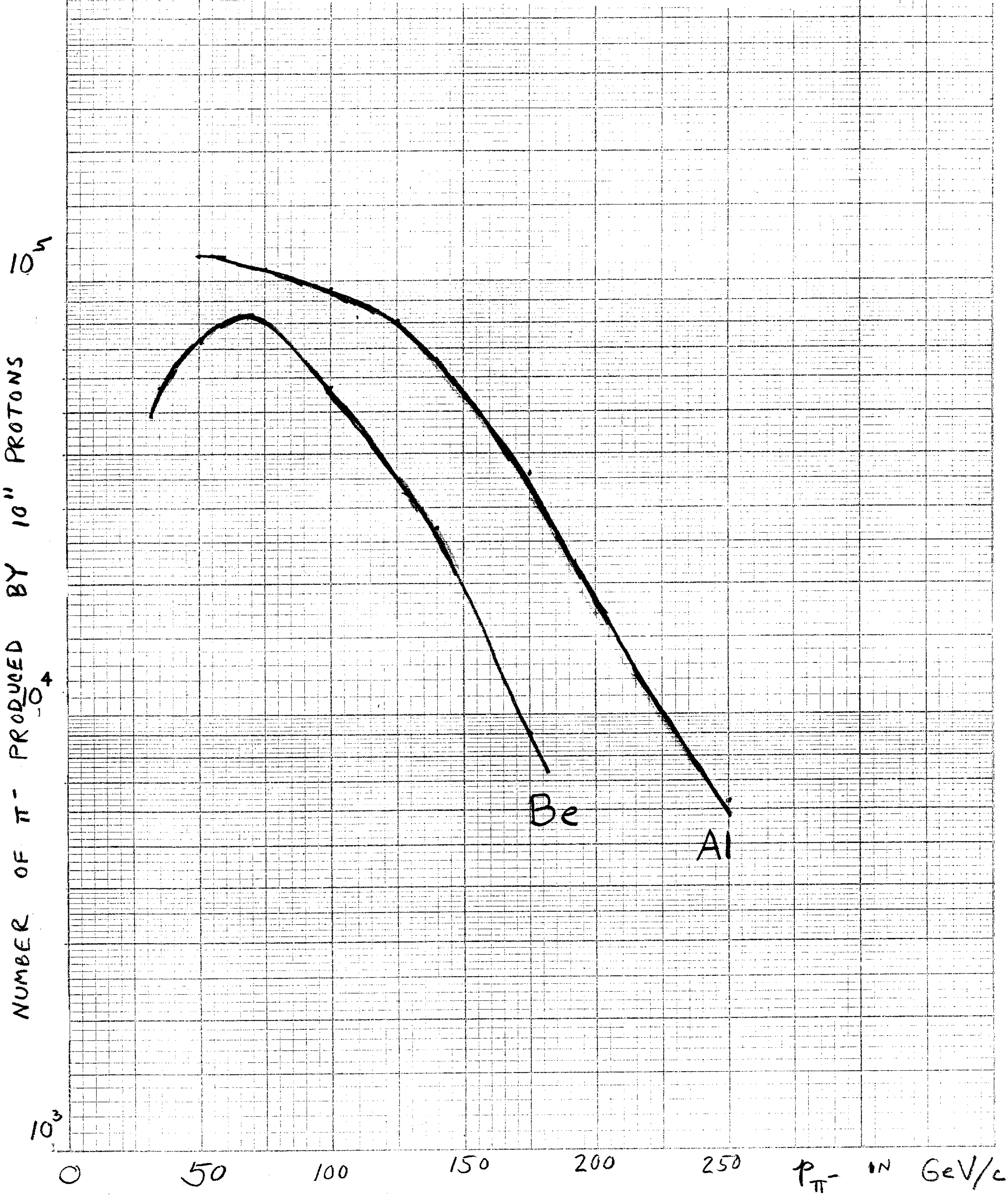
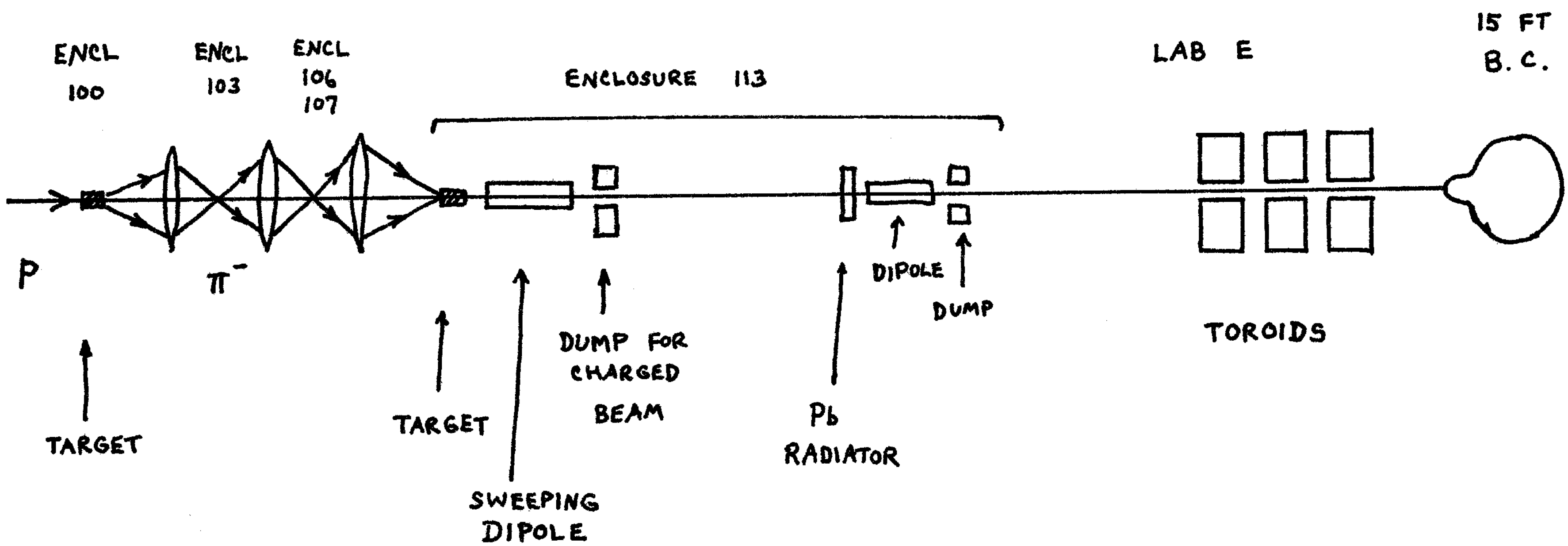


FIGURE 2

Schematic of the neutral kaon beam for the 15-foot chamber. Not drawn to scale.



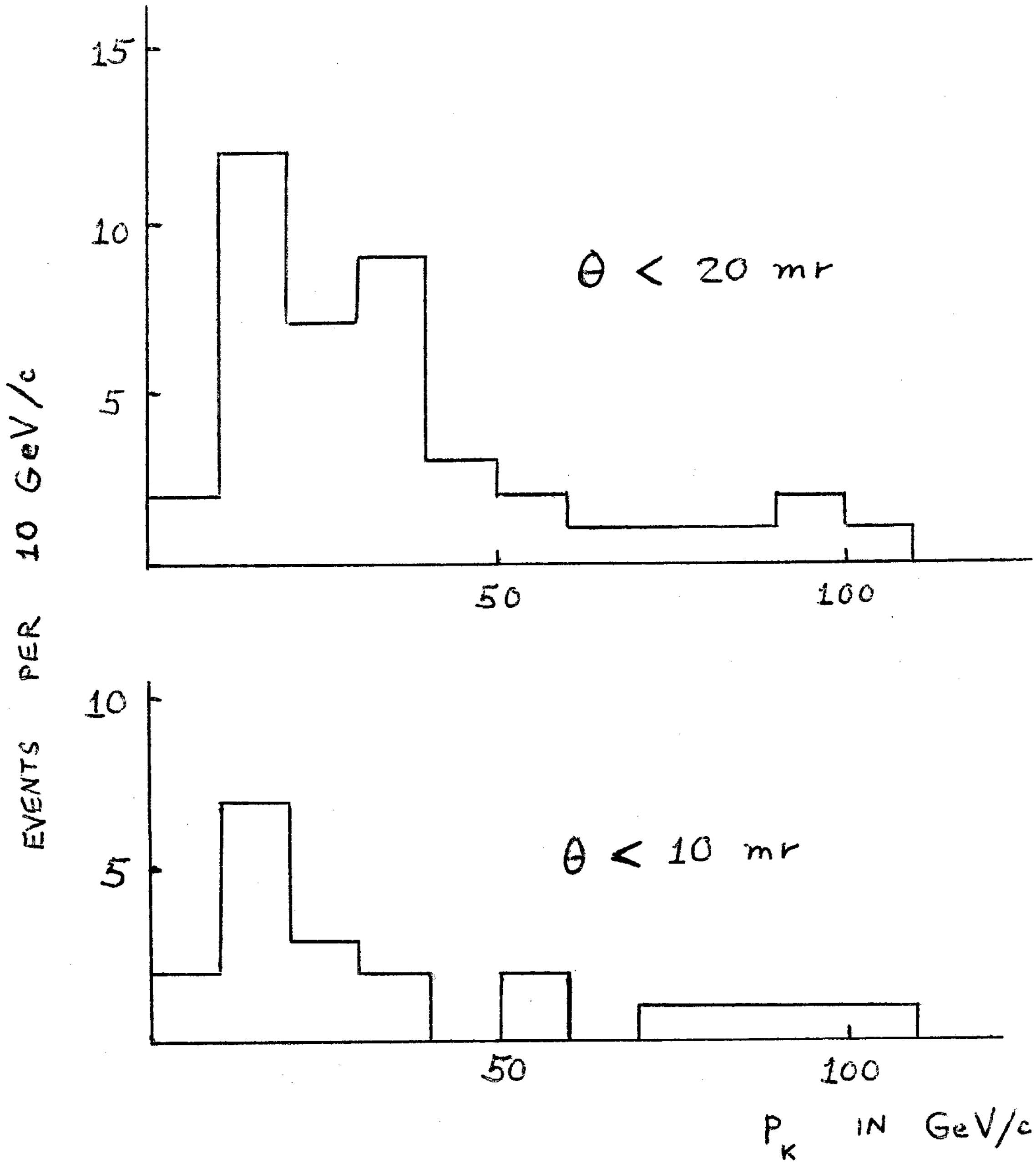


FIGURE 3. Yield of K_s^o from π^-p at 250 GeV/c. Data are from E-234, with about 4x104 pions into the 15' bubble chamber at Fermilab. θ is the laboratory production angle of the K_s^o

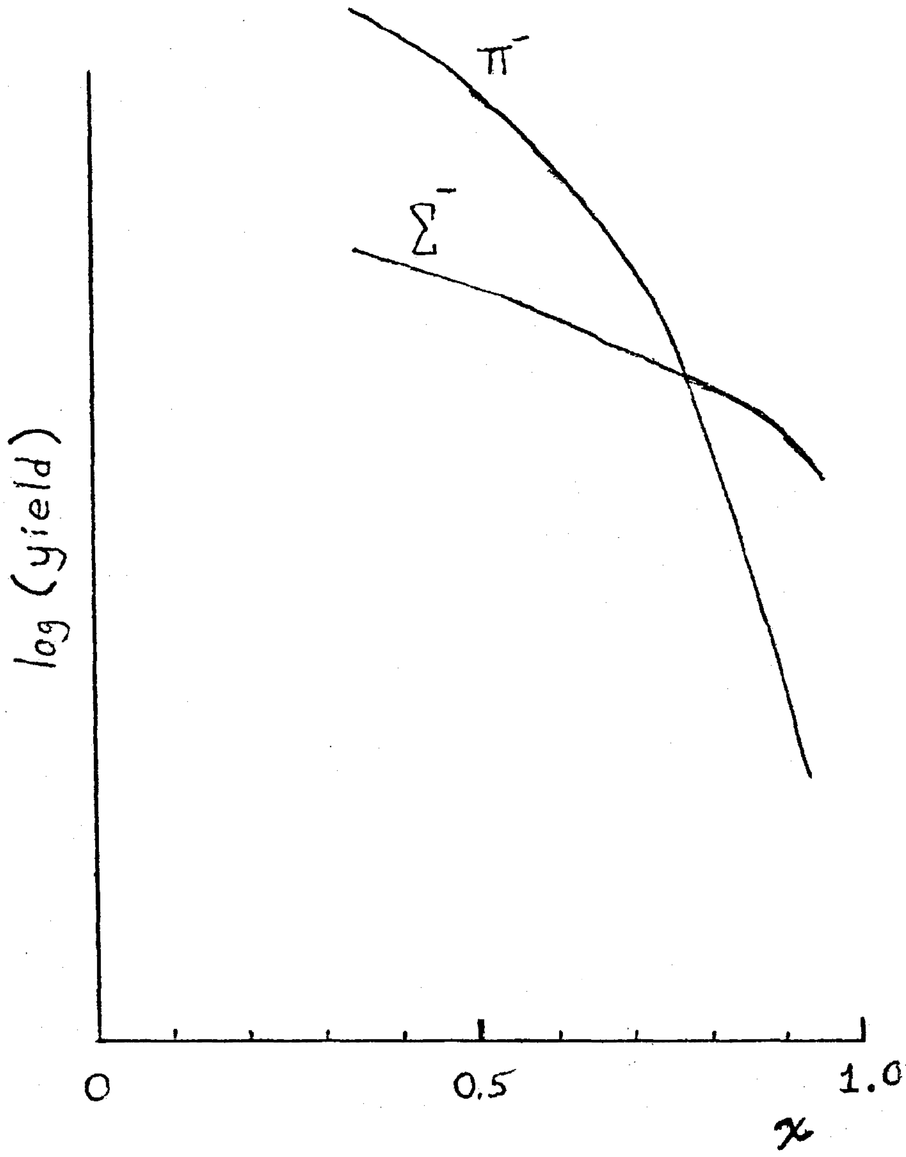


Fig. 4 Yield of π^- and Σ^- from protons.

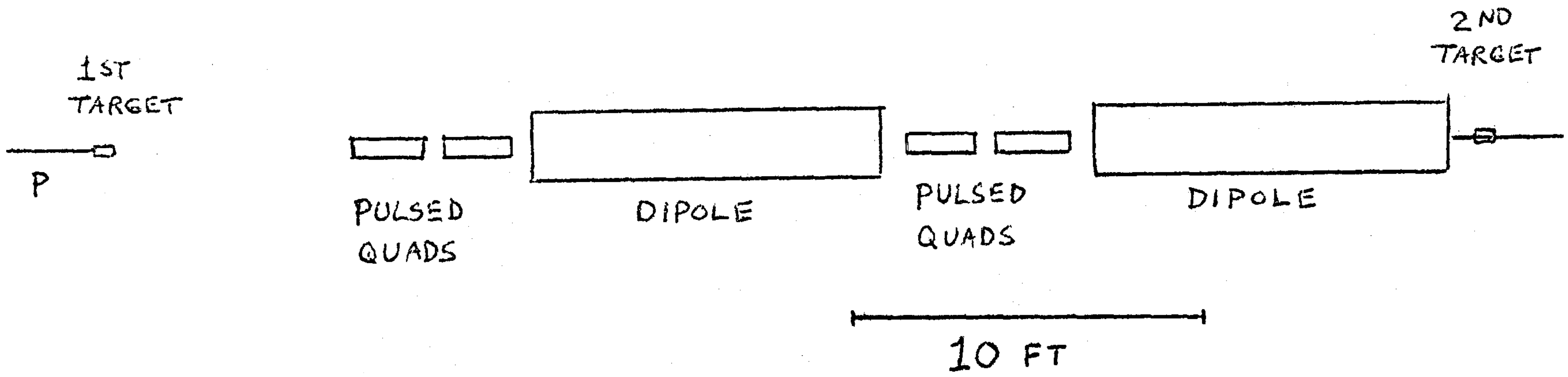


Fig. 5 Schematic layout for double targeting using pulsed quadrupoles in Enclosure 100.